Ocean Circulation and the Carbon Cycle

Some basics

- The world's oceans contain 50 time the amount of carbon as the atmosphere
- Most of this carbon (90%) is in the form of the bicarbonate ion

$$CO_2 + H_20 \leftrightarrow H_2CO_3(aq)$$
$$H_2CO_3(aq) \leftrightarrow H^+ + HCO_3^-$$
$$HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$$

Most of the removal of CO_3 in the oceans is by the creation of carbonate $CaCO_3$ by organisms secreting shells. Most of the free hydrogen radicals are also taken up in mineral reactions.

This carbon dioxide sink is the final resting place for the majority of the carbon dioxide released by humans so the basic question is how rapidly does this uptake of carbon occur.

Ocean Circulation

- Only the top 75 meters of the ocean is well mixed, in general this mixed layer is ~30 meters deep in the tropics and grows thicker with increasing latitude. Below this depth, the motion of the ocean is thought to be driven primarily by thermohaline circulation. That is to say that temperature and salinity differences lead to density differences that control the advection of water in the world's ocean basins.
- Surface waters exchange 1/7th of their carbon with the atmosphere each year. However despite this high turnover, the limited volume of the mixed ocean limits it ability to take up additional carbon dioxide. It is the transfer of excess carbon from the shallow to the deep oceans by both water flow (advection) and by diffusion that determine the short-term response of the oceans to increasing carbon dioxide in the atmosphere.
- The carbon content of the oceans is largely the result of the reaction of CO2 from volcanic activity with the minerals that comprise the earth's crust.
- As mentioned before a major removal of carbon from the oceans is the formation of $CaCO_3$ by biological activity of secreting shells.

$$CaCO_3 \leftrightarrow Ca_2^{2+} + CO_3^{2-}$$

This carbonate comes in two types: calcite and aragonite (which is the less stable of the two). The rate at which this $CaCO_3$ is exported from the surface waters is probably limited in most areas by the rate at which N and P are transported upward and in some areas by the availability of Fe. This is because these processes are driven by marine photosynthesis.

Influxes

Carbon also arrives in the oceans from runoff from the continents. The input of organic carbon is thought to be 0.4 to 1.0 GTC per year while dissolved carbon could be an additional 0.2 GTC per year.

Accumulation

As material accumulates on the oceans, carbon is put into long-term storage on the ocean floor at a rate of approximately 0.2 GTC per year that will probably not change much on human timescales.

Timescales

The mixed layer is in equilbrium with the atmosphere on timescales of about a year. However, deep oceans have much longer turnover times. The most remote portions of the ocean may not exchange carbon with the atmosphere for 1000 years. Turnover times for areas of the ocean with depths greater than 1500 m are

Atlantic	275 years
Indian	250 years
Pacific	510 years